Nozomi Cis-Lunar Phase Orbit Determination*

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EXTENDED ABSTRACT

orbit determination

Japan's Institute of Space and Astronautical Science (ISAS) launched Nozomi, its first mission to the planet Mars using the newly developed M-V launch vehicle on July 3, 1998. Scientific objectives of the mission are to study the structure and dynamics of the Martian upper atmosphere and its interaction with the solar wind. Nozomi is a cooperative mission between ISAS and the National Aeronautics and Space Administration (NASA). The NASA contribution includes navigation and tracking services provided by the Jet Propulsion Laboratory (JPL).

The spacecraft also serves as an engineering demonstration of basic technology for planetary exploration. One of the new technologies was a unique trajectory, developed by ISAS, which used solar gravitational perturbations at the weak stability boundary as an aid to achieve an Earth-Mars transfer orbit. This trajectory saves approximately 120 m/s of ΔV compared to direct hyperbolic insertion and is considered an enabling technology for the mission. Nozomi was the first spacecraft to employ this trajectory and provided on-orbit validation of the technique.

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The trajectory was achieved by initially placing the spacecraft in a highly elliptical cis-lunar phasing orbit. Six maneuvers were performed during this period to correct injection errors and target an outbound lunar swingby in September 1998. The gravity assist from the lunar swingby raised apogee to the vicinity of the weak stability boundary. After three more targeting maneuvers, Nozomi performed an inbound lunar swingby followed immediately by a powered Earth swingby in late December 1998. A 420 m/s Trans Mars Insertion (TMI) burn at the final Earth periapsis was intended to place the spacecraft on a heliocentric trajectory leading to Mars orbit insertion in October 1999.

Orbit determination for Nozomi is performed in parallel by both ISAS and the Multi-Mission Navigation (MMNAV) group at JPL. This was an advantage for the mission because each group would generate solutions based on data collected from their respective tracking networks. Spacecraft events, such as sequence uplinks and maneuvers, were generally scheduled during passes at the Usuda tracking station in Japan. As a result, maneuver design and reconstruction was derived from MMNAV solutions based on JPL tracking data obtained immediately prior to or following maneuvers. Data was also exchanged between ISAS and MMNAV so orbit determination could be performed on joint data sets in support of critical targeting late in the cis-lunar phase.

In this paper, information regarding the MMNAV orbit determination effort for the first six months of the mission is presented. The spacecraft trajectory is characterized first, followed by a discussion of the orbit determination estimation procedure and models. Results from selected orbit solutions are presented and compared against reconstructed trajectories.

One area of emphasis in this paper is orbit determination in the vicinity of the weak stability boundary. Precise navigation was necessary to target the second lunar swingby and the powered Earth swingby. Delivery accuracy of 150 m was required for these critical encounters, but a number of factors contributed to the general degradation of orbit determination accuracy. This included the fact that the spacecraft was at apogee, at a range of 1.7 million km and moving at less than 1 km/sec perpendicular to the line of sight. Nozomi was also close to zero degrees declination where there are known limitations on orbit determination performance. Finally, S-band tracking data was acquired through the

Nozomi backup low gain antenna. This antenna is offset from the axis of this spin stabilized spacecraft and superimposed large signatures in the Doppler and range data.

These difficulties were overcome by combining long data arcs, spanning several maneuvers, with a high fidelity solar pressure model. The model included a physically accurate representation of the spacecraft structure and a high time resolution orientation model. Observation modeling included the removal of the spin induced Doppler bias, spin signature and per pass correction of range calibration errors applied for data leading up to critical events. As a result, all orbit determination goals were met.

A second area of emphasis in this paper is the JPL tracking and orbit determination effort in support of the TMI maneuver. TMI occurred out of contact with ground stations and the JPL Goldstone tracking complex had the first pass following the burn. As a result, MMNAV had the responsibility to make a rapid assessment of the maneuver performance. MMNAV made the determination that a 100 m/s under burn had occurred and promptly informed ISAS via voice lines. ISAS immediately began preparations for a correction maneuver (TMIc), which had to be performed during the next Usuda pass. The near real time assessment by MMNAV provided accurate antenna frequency and pointing updates for the spacecraft acquisition at Usuda and the close coordination between the two agencies enabled the design and successful execution of the TMIc maneuver.

Propellant consumption during the correction burn dictated that the mission be redesigned. ISAS developed a new plan which adds 3 full solar orbits, two Earth swingbys and one lunar swingby with arrival at Mars in January 2004. The final Mars orbit will still enable the mission to achieve all of its science objectives.